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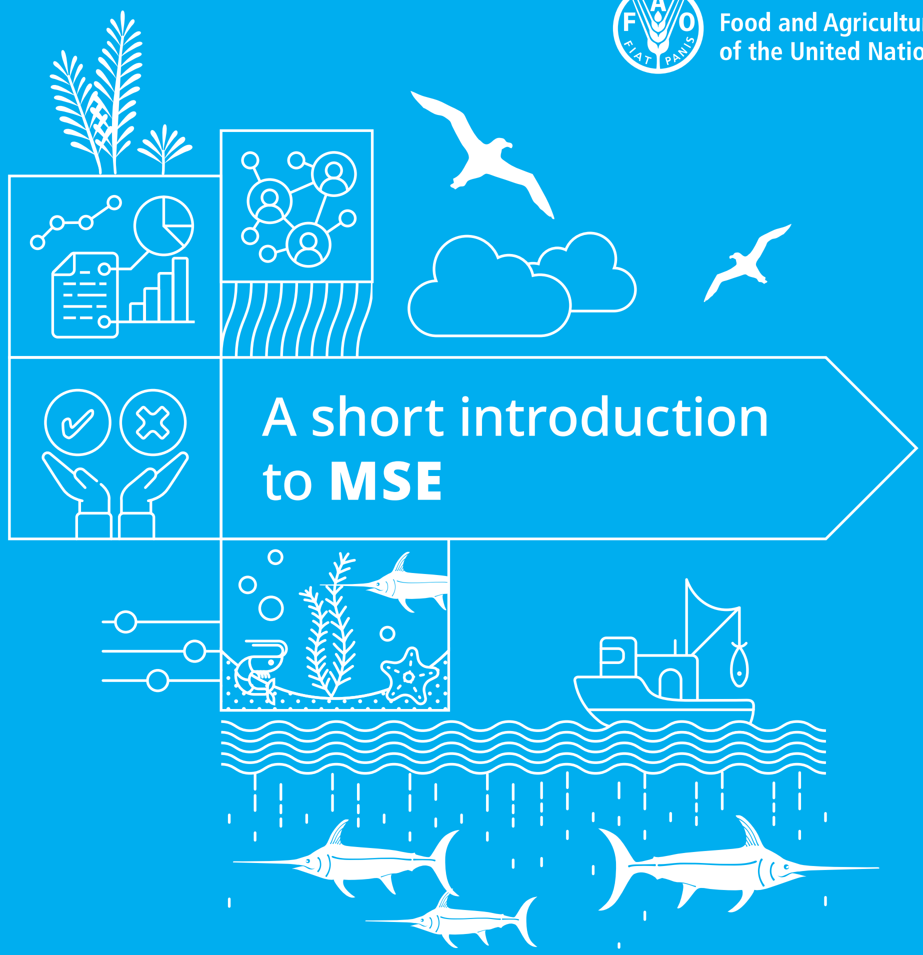


A short introduction to **MSE**

INTRODUCTION

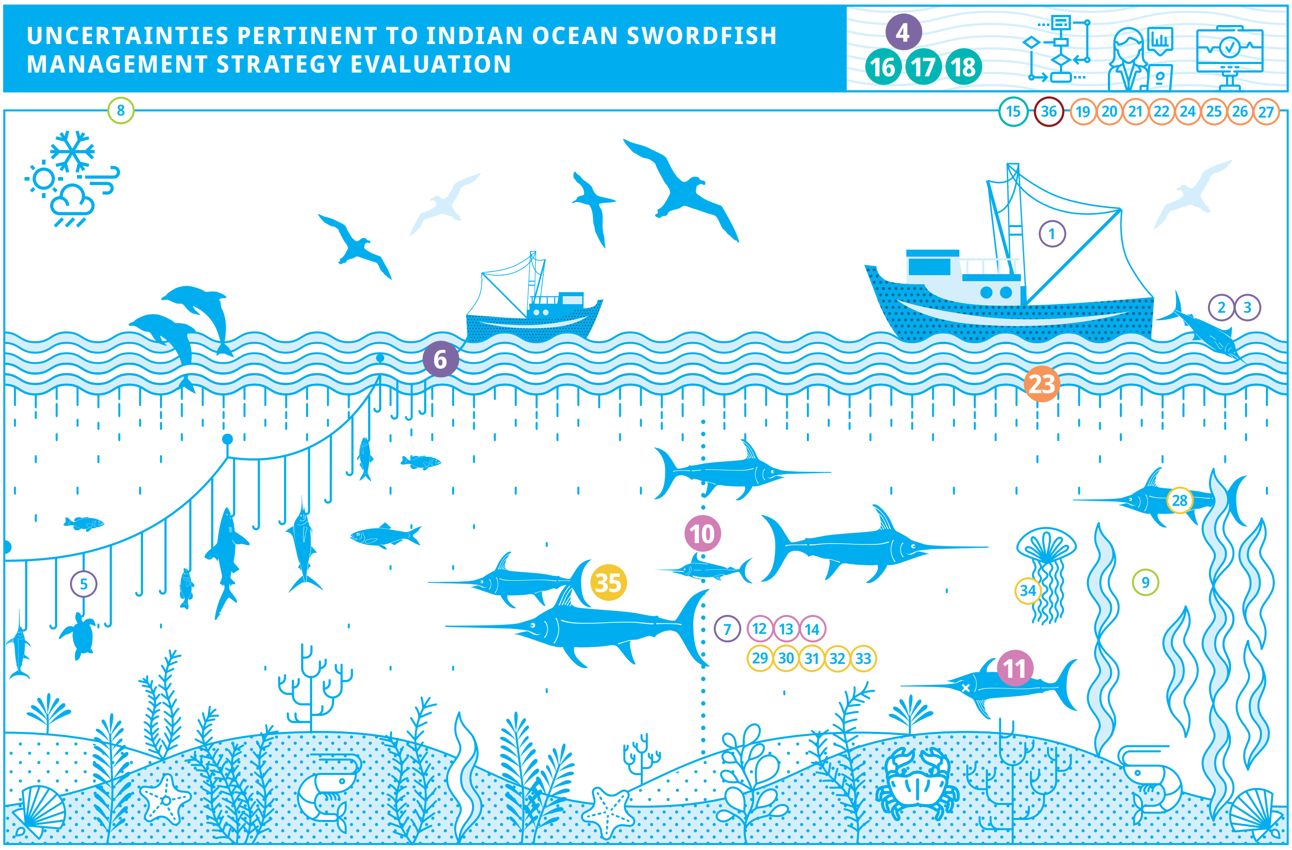
Fisheries are a complex dynamic system. We don't know exactly how it functions and interacts with the environment and society.

Our ability to predict how stocks will respond to exploitation is limited and control mechanisms we have are imperfect. Finding management solutions through trial and error is difficult for various reasons, not to mention the ethical ones (conducting experiments on fisheries would entail deliberately depleting them and risking stock collapses). Thus, simulations are an attractive option. This is the essence of the Management Strategy Evaluation (MSE) approach — it's a way to identify those exploitation strategies that are likely to achieve management objectives while avoiding unacceptable risks.

Management Strategy Evaluation

Management strategy evaluation represents a paradigm shift — no longer beholden to the accuracy of stock assessments, it is a step towards proactive and robust decision-making. In practice, **MSE is a type of quantitative risk assessment** that starts with a relatively narrow scope — ecosystem, or explicitly social, cultural, or economic aspects need to be considered separately, as the models generally are only able to account for a fraction of uncertainties *(Figure 1)*. In the Indian ocean case study that is used here for illustration, nine sources of uncertainties were consid-

INDIAN OCEAN
Tuna
Commission



SOURCES OF UNCERTAINTY

UNCERTAINTIES CONSIDERED IN MSE ●
UNCERTAINTIES EXCLUDED FROM MSE ○

CATCH

1. Catch mis- and under-reporting
2. Discard mortality
3. Unreported discards
4. **CPUE standardisation/conflicts**
5. Bycatch
6. **Selectivity; gear selectivity/ catchability changes by fleet (e.g. gear/equipment changes)**
7. Changes in effort distribution: seasonal dynamics (stock/fleet)

ENVIRONMENTAL

8. Climate change and/or increased variability's potential to change population dynamics
9. Environmental forcing; environmental considerations and behaviour

LIFE HISTORY TRAITS

10. **Growth and maturity**
11. **Natural mortality (M)**
12. Sex dependent migration: spatial sexual segregation of the stock (real or observed)
13. Fecundity
14. Stock structure and mixing; group dynamics, skipped-spawning, density dependence

MODEL

15. Model complexity
16. **Steepness**
17. **Alternative data weights (length comp); length compositions effective sample size**
18. **Scaling**

SOCIO-ECONOMIC

19. Economic uncertainty; market and other economic data to be used in assessing the risks
20. Uncertainty over objectives; management objectives
21. Uncertainty over reference points; lack of information on virgin stock levels
22. Risk attitudes of managers
23. **Catchability increase**
24. Effect of regulations on effort; minimum size recommendation; implementation options
25. Social impacts on local communities; impacts/effect on small local communities
26. Illegal fishing; regulations that change the balance of effort between legal and illegal fisheries
27. Effect of regulations on species; impacts and effect on global distribution of the species.

POPULATION STRUCTURE

28. Oxygen minimum zone, i.e. vertical displacement of individuals
29. Cyclic movement of adult swordfish
30. Changes in migration; environmental factors that influence migration patterns
31. Spatio-temporal dynamics of sub-populations
32. Existence of genetically distinct and vulnerable sub-stocks
33. Sex ratio
34. Interactions with other species
35. **Recruitment Variability Recruitment failure of success (cyclic trends/regime shift)**

REFERENCE POINTS

36. Dynamics of reference points; stationarity, cohort year effects, density dependence

Figure 1. *Showing nine uncertainties that are part of the MSE (bold) vs. those that could not be accounted for.*

ered. The choice of uncertainties is informed by the stakeholders's beliefs as to what is important. So while we should not overinterpret MSE results as comprehensive, they are informative about relative performance of management strategies. Evidence from fisheries that are managed via havest strategies that have been tested in simulations supports a view that testing offers clear advantages over no testing. Harvest strategies or management procedures are *algorithms* that partially replace a formally social decision-making process — for example, a management procedure might specify which data is to be collected, how should it be analysed, and what decisions should *automatically* follow.

The MSE process is synonymous with better management, more inputs from stakeholders, better monitoring and implementation, and safer fishing pressures. Management procedures introduce a stability that is welcomed by the industry that might see additional benefits from a higher likelihood of being certified as sustainable by the Marine Stewardship Council (MSC).

FUTURE CONE

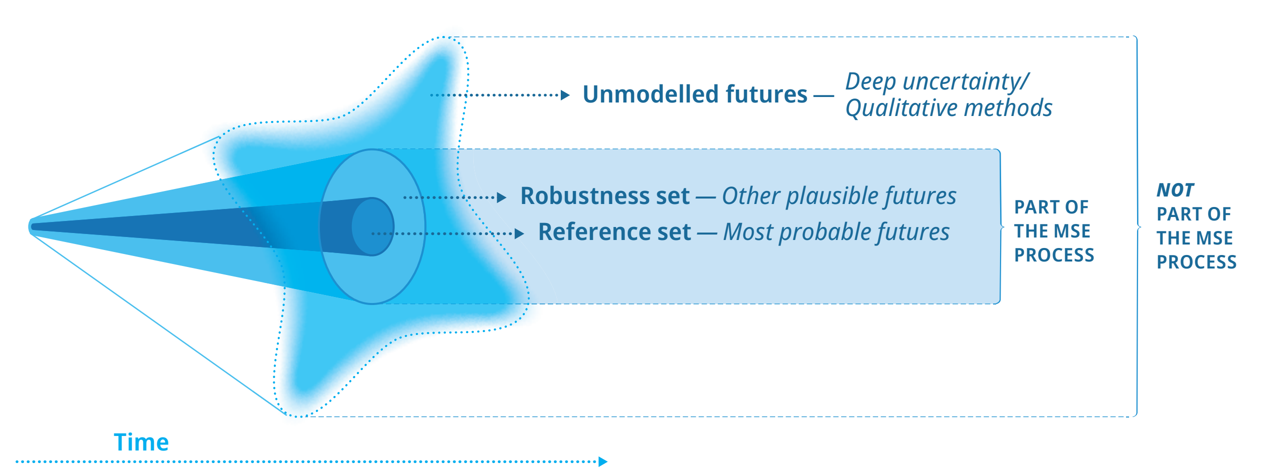


Figure 2. *Imagining possible futures: reference scenarios, robustness scenarios, and deep uncertainty. The reference scenarios in our swordfish example are generated by nine uncertainties. Each uncertainty is represented by 2 or 3 discrete alternatives (e.g. steepness is either 0.6, 0.75, or 0.9).* ***Out of the full grid of 2592 OMs, only 110 passed the plausibility test****. These 110 were resampled to generate 500 simulated worlds.*

The MSE process has the potential to generate other benefits — it can improve understanding and reliability of stock assessments, offer a basis for prioritization of research and data collection needs, it can facilitate communication on trade-offs inherent in fisheries management and help reach agreement among stakeholders.

Operating Models

To perform these experiments comparing management procedures, a virtual world — called **operating model (OM)** — is constructed, based on beliefs of how the real world works, and how it will work in the future. Ideally, represented beliefs would reflect uncertainties in various types of relevant knowledge (expert, local, indigenous) but most commonly the models are essentially copied from stock assessments (augmented with extra information or assumptions). Subsequent stock assessments tend to result in substantial updates in the beliefs about the stock and its history, hence MSE should probably be re-conditioned on newer stock assessments at least once a decade (even if no warning signs were detected that could result in invoking **'exceptional circumstances'** clauses such as recruitment failure, suspected large IUU landings, or critical issues with CPUE data). Climate change is likely to present an additional challenge to stock assessments or any model that relies on past data, stationary assumptions, and processes discerned in the context of the past to predict the future — in the context of fast changes, the MSE offers a way to look for management procedures that minimise regret under uncertainty, if operating models are constructed more imaginatively than traditional stock assessments.

Two types of virtual environments are generally distinguished in the realm of OMs: **a reference set and robustness trials** *(Figure 2)*. A reference set starts from a smaller set of possibilities and projects forward the "most probable futures". Robustness trials usually refer to opening up of assumptions in the reference set and hence simulating a wider set of "other plausible futures" and hence encompass more challenging circumstances for management procedures to cope with. It might become difficult to find strategies that achieve a wide range of management objectives in all robustness scenarios. It is key that managers and stakeholders agree on what constitutes a satisfactory performance for a management procedure, preferably agreeing on what risks are unacceptable before seeing the results of evaluations.

Simulated worlds might differ from each other and also from the portrait of the real world familiar from the most recent stock assessment — extra assumptions or information might make historical or future projections with OMs different from those obtained with stock assessment models. Such differences can be expressed in beliefs around resilience of the stock to exploitation (captured by the **steepness** parameter), population levels the stock can reach in the long term in the absence of fishing (one definition of **virgin biomass**), the maximum sustainable yield (**MSY**) that can theoretically be extracted indefinitely, the variability in abundance from year to year. In particular, this means that **reference points differ from one OM to another.** *Figure 3* shows a distribution of reference points across OMs (left violin plot), as well as differences in how OMs represent the present (center) and what is possible to achieve in the future under MP6 (right).

PAST, PRESENT, FUTURE

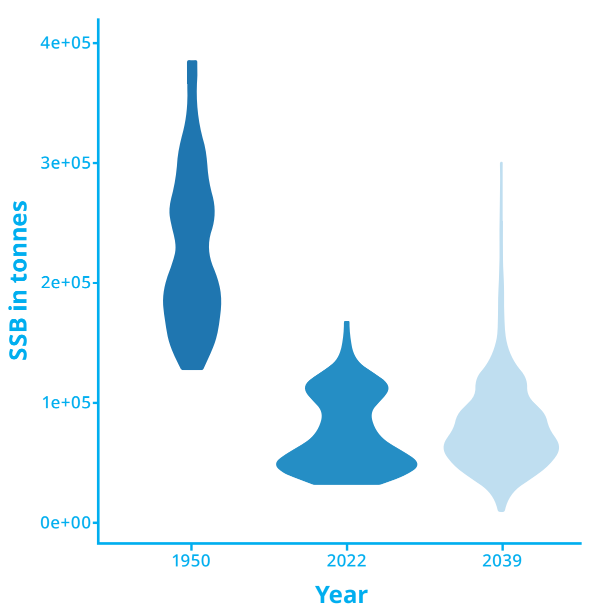


Figure 3. *Past, Present, and Future.*
We take the 1950s as a reference, or proxy, for the unfished state, or B0. One of the management objectives is to ensure that the biomass does not fall below 20% of B0 in each of the OMs. The management objectives are based on MSY estimates that range from 13% to 37% of B0 — reducing the stock to less than a quarter of its original size is a success story in half of the OMs.

The advantage of simulations is that we know a lot about each simulated world, because we built it. In particular, we know what MSY is possible in each, and it makes sense to evaluate strategies with respect to MSY-based values native to each operating model *(Figure 3)*. Further, for each virtual world a management procedure usually includes its own understanding of the simulated stock it 'observes' through the prism of **simulated observation data** and a simplified estimator (although in some MSEs the estimator is not simplified at all and the full traditional stock assessment model is ran every iteration when a harvest decision has to be made — this is very computationally expensive). Empirical management procedures don't need an estimate of stock status, they set harvest levels based on observed data trends, such as CPUE or a larval index.

The aim is to reflect imperfect knowledge, but it is often argued that while being tested, the MPs are too well informed about the simulated stock. **The estimator often replicates the operating model's assumptions about what drives the population dynamics** (whereas in reality we don't know how the real world works) and the simulated observations are often deemed "too good" even as the level of added noise appears to mimic historical data. Being too "well-informed" about their respective simulated worlds makes it easier for MPs to achieve management objectives in virtual worlds — it is like giving a student questions before the test. However, if MPs were routinely picked based on insufficiently rigorous tests, we would expect to see more failures in the real world.

The management procedure operates in two steps. First, it learns something about the simulated stock (e.g. from simulated observations and an estimation algorithm). In the second step, it decides what management actions should be adopted via an algorithm called **Harvest Control Rule** (HCR) *(Figure 4)*. For example, if an MP estimates that the stock (in a particular year, in a particular virtual world) is below MSY, its response could be to reduce fishing pressure.

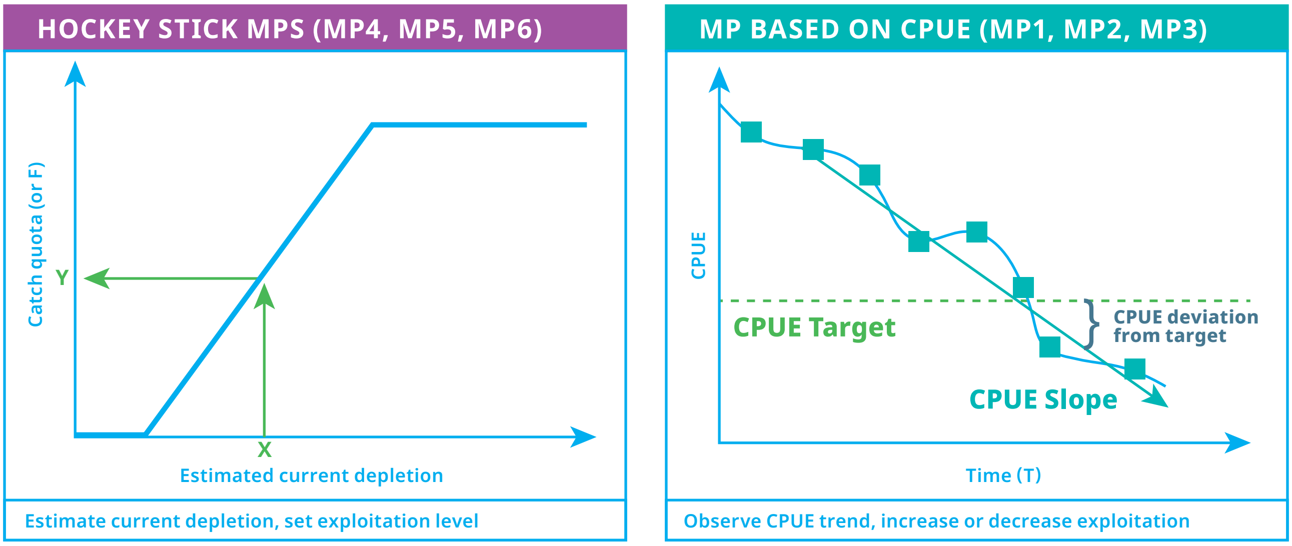
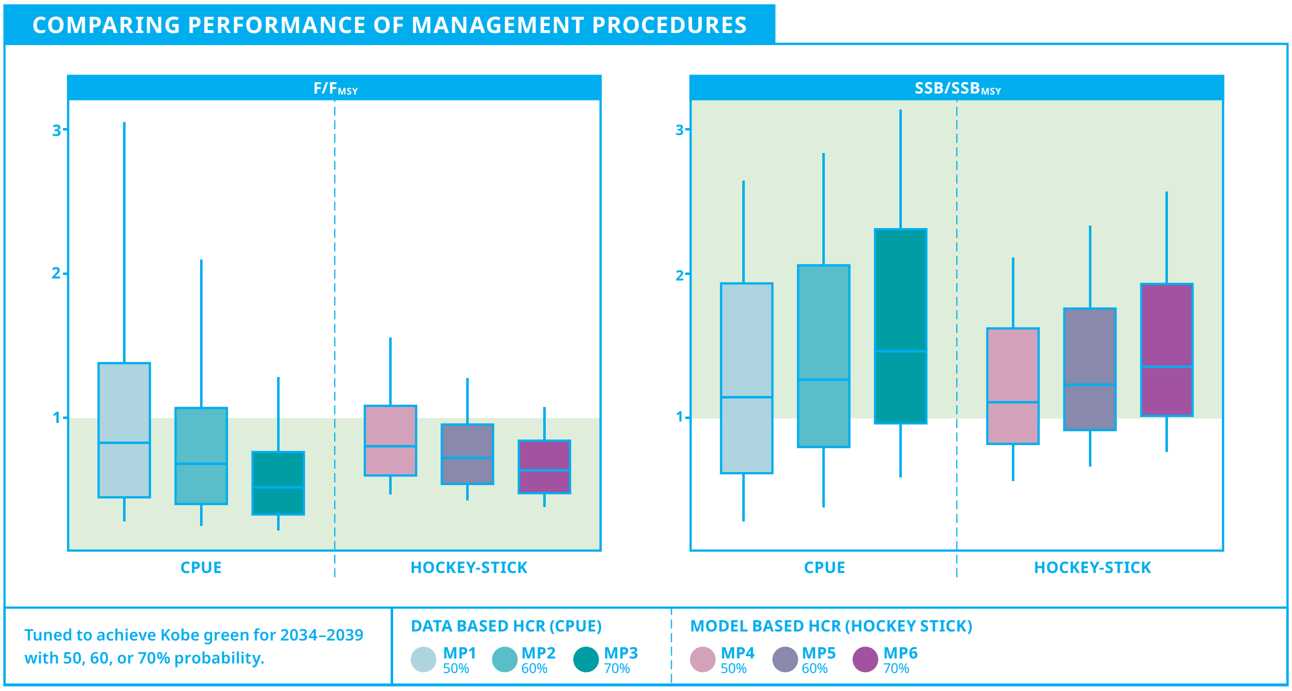


Figure 4. *CPUE and Hockey Stick: two types of HCRs in our swordfish MSE illustration. Both set TAC for 3 years, changing it by no more than 15% at a time.*

Harvest Control Rules & Tuning

Harvest Control Rules are devised with a degree of flexibility, and can be made more or less reactive via tuning parameters: adjusting aspects, such as the sensitivity of a management response to stock decline. An HCR algorithm can be tuned until the algorithm is seen to 'work' in simulations — for example, it manages to maintain the stock within the Kobe green zone with 70% probability, within an agreed timeframe.

The values of the tuning parameters can have a greater impact on the performance of the management procedure than the general principle behind the algorithm *(Figure 6).*



20% of simulations are not shown; the whiskers cover the interval from 10–90%, the box regions show 50% of simulations (second and third quartile).

Figure 5. *Box plots. Comparison of performance in relation to F_{MSY} and SSB_{MSY}.*

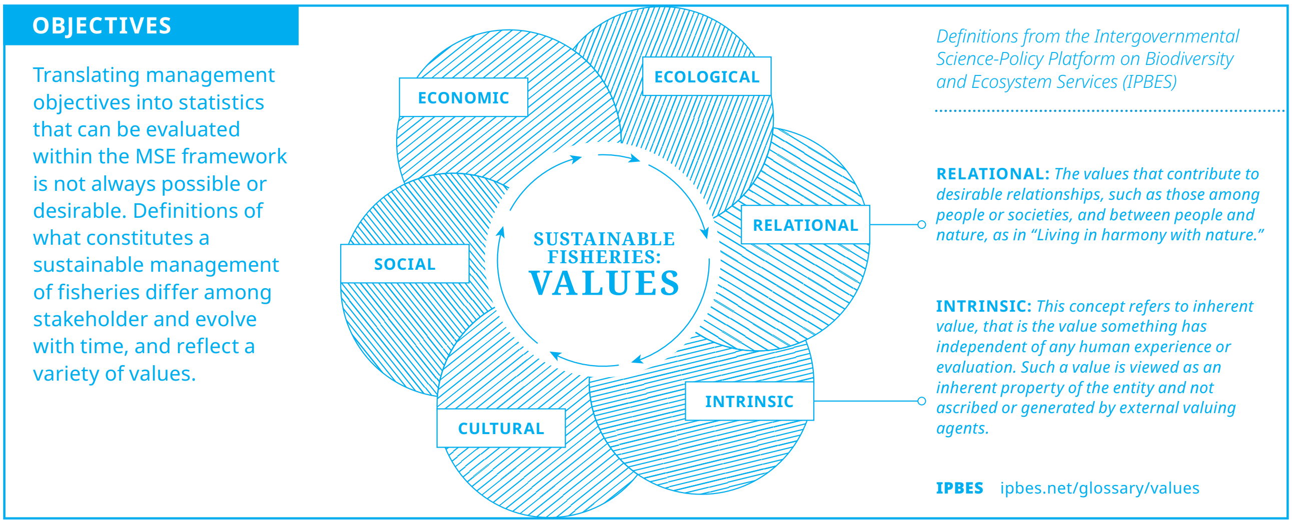


Figure 6. *The management objectives for sustainable fisheries are shaped by a variety of* ***values****. The relationship between these values and statistics used to represent them in the MSE model is often unclear.*

The difficult part is to identify **management objectives** and translate them to an extent that is possible into statistics that could be monitored in the simulations to see how various management procedures perform. Not all management objectives are intuitive to translate; fairness or equitability of access, maintaining ecological function, safeguarding employment, or preservation of cultural values are challenging but not always impossible *(Figure 6)*. Some objectives related to "safety" need to be expressed in terms of risk: the stock should avoid low levels with high probability. MPs that do not meet pre-agreed safety criteria for the reference set of OMs should be rejected. One of the key advantages of the MSEs is their ability to **quantify tradeoffs among different objectives** *(Figures 7, 8, and Table 1).*

Management procedures should be relatively realistic, that is, the simulated data that is

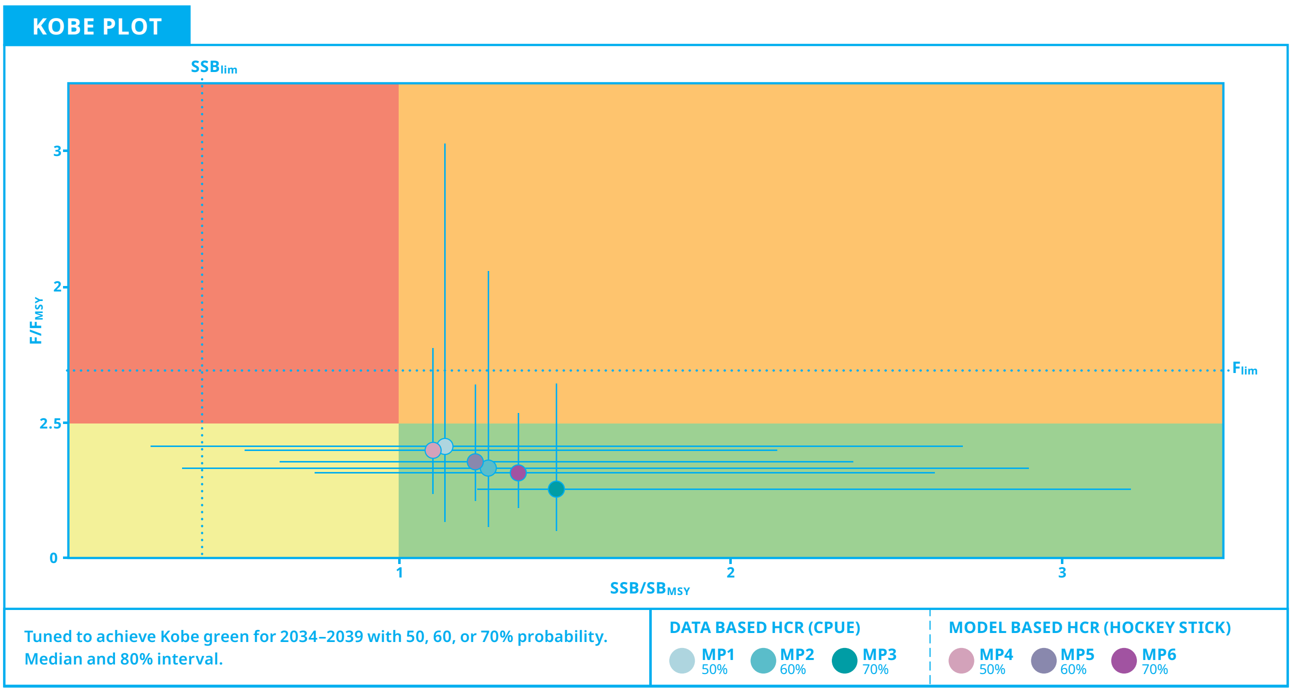


Figure 7. *Kobe quadrants. Kobe green, or the safety region, is where SSB is above SSB_{MSY} and F is below F_{MSY}.*

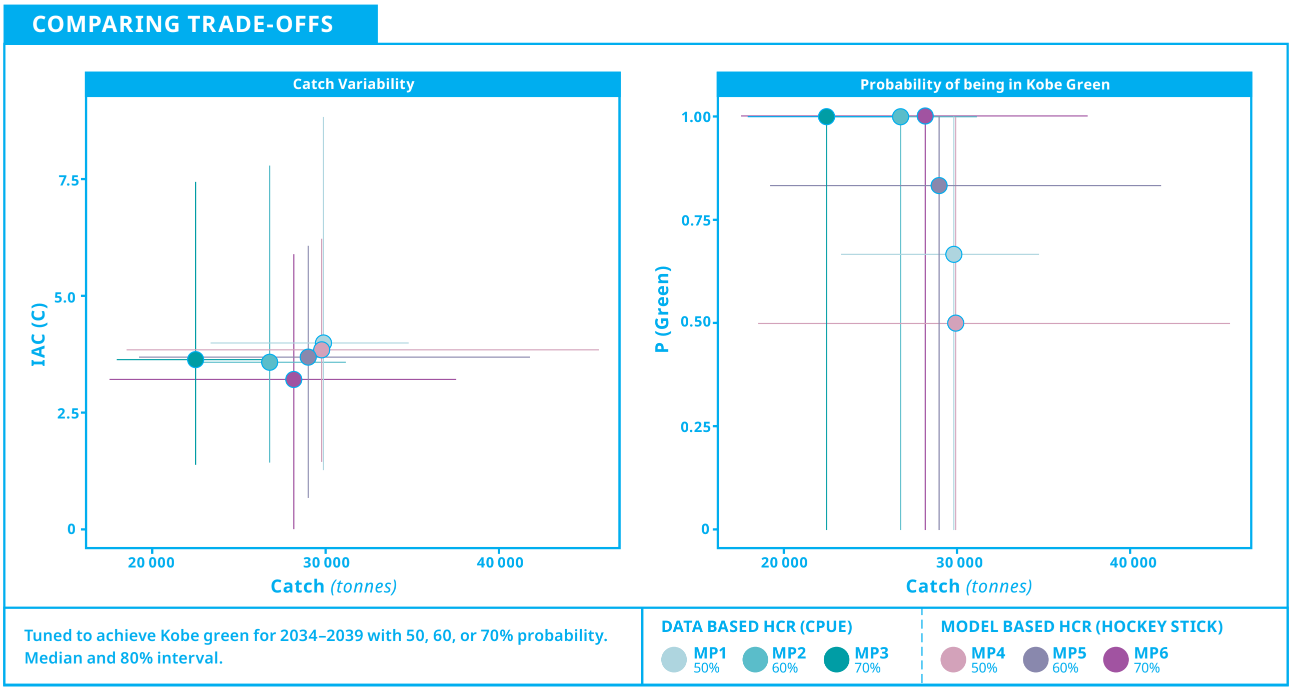


Figure 8. *Pairwise trade-offs, between Catch/Catch Variability (left) and Catch/Safety (right).*

available to the management procedure should have an equivalent in the real world, for example, a particular CPUE index or a fisheries independent survey. Simulations can help **identify biases in our perception of management's success** and tell us how these biases depend on the quality/quantity of data and/or on the simplifying assumptions we make in the estimating model.

Table 1. *Performance of six MPs measured by five statistics. The MPs are sorted by tuning level. Darker shading represents better performance, however, the boundaries which determine shading are arbitrary. Moreover, quilt colour coding creates a false sense of comparability between categories that are valued differently by different stakeholders.*

Harvest Control Rule (HCR)	Tuning Level	Management Procedure (MP)	Performance Measure (median values)				
			SSB/SSB_{MSY}	Probability Kobe Green	Proportion of simulations SSB > 20% of SSB0 (unfinished)	Catch (tonnes)	Catch variability (AIC)
CPUE	50%	MP1	1.13	67%	63%	29900	3.99
Hockey Stick		MP4	1.10	50%	69%	29900	3.84
CPUE	60%	MP2	1.27	100%	71%	26800	3.58
Hockey Stick		MP5	1.23	83%	78%	29000	3.65
CPUE	70%	MP3	1.47	100%	80%	22500	3.68
Hockey Stick		MP6	1.36	100%	89%	28200	3.21

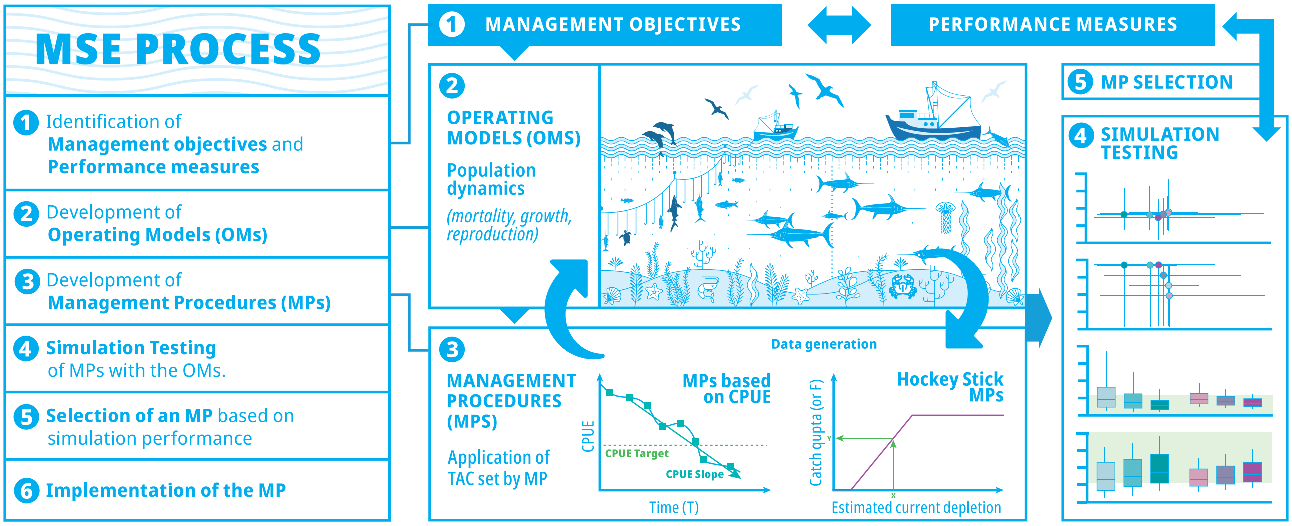


***Figure 9.** MSE framework*

IN SUMMARY

MSE enables exploring a wider set of questions than traditional stock assessments and facilitates agreeing on management procedures that are robust to a wider range of uncertainties than previous management regimes, in commercial or industrial fisheries.

MSE approaches necessitate resolution of a variety of scientific disputes, which itself can be a benefit. It can show that some of the uncertainties that have been considered important are in fact unlikely to have impacts on management objectives, thus lessening conflicts and **resolving differences in beliefs**.

Other philosophical questions remain open. How to decide on the plausibility of operating models is still an active area of research. Should operating models have predictive powers? How should they be validated and how often? When can we say that MPs have been sufficiently tested and who gets to say it?

How can we deal with the barriers to participation presented by the technical nature of the MSE approach? Open source approaches to sharing the code are helpful but do not **empower key stakeholders to critically engage with the process**. Reproducibility is an issue even for other modellers; results are rarely run by more than one team.

While helpful in resolving some disagreements, MSE rarely addresses questions of equity. Harvest control rules that are evaluated within MSE usually say little or nothing about how the total catch should be allocated among different users of the resource. However, there have been examples where MSE was explicitly designed to tackle these issues.

The socio-economic benefits of MSE are not guaranteed but depend strongly on how the MSE process is set up, especially, on its **transparency, inclusiveness, and effort to improve communication**.

For further explorations, visit the MSE Shiny app and Website created by iotc.

MSE Capacity Building Tools
IOTC Shiny app

MSE Tool Website
iotc.org/educational-tools

REFERENCES AND RESOURCES

Videos

The easiest place to start learning about MSE is perhaps watching a four minute YouTube video called '**Demystifying MSE: Management Strategy Evaluation**'.

A couple of excellent longer lectures focus on real-world examples, but offer general insights and showcase the depth and breadth of management contexts where MSEs have been used. The first is a film-length video: **ICCAT Bluefin MSE**. The second, an hour-long video, presents several MSE **case studies from NOAA** with references to indigenous and traditional management options, as well as ambitious attempts to model ecological complexity within the MSE.

Other Shiny Apps

Listed in order of complexity

The **North Atlantic Swordfish MSE shiny app** developed for ICCAT is a simple illustration. It contains an infographic with sources of uncertainty that are included in the MSE, versus those that are not considered quantitatively but have been identified by stakeholders as important. It introduces ways to visualise the reliability of data, knowledge, and models used in the MSE, and proposes simple ways to compare results across OM that represent key uncertainties about recruitment, natural mortality, etc.

A highly recommended tool is '**Ample: An R package for capacity building on fisheries harvest strategies**'. This is a great place to start learning about harvest strategies and how they cope with uncertainty. One downside is that it requires R studio, but the three clearly-structured interactive shiny apps can be accessed with only a couple of lines of R code.

Ample, Spample, and Pimple: From Ample, one can cross the bridge to **Spample** — an attractive app developed for exploring MSE results testing alternative candidate Management Procedures (MPs) of south Pacific albacore. These apps developed by the Pacific Community are really excellent, and it is recommend to also check out the app for skipjack, called Pimple.

Slick, the most complex of these apps, is for Atlantic bluefin MSE. Luckily, the developers of Slick were able to bring in graphic designers, as well as communication experts — it is the most sophisticated effort to explore candidate management procedures in a myriad of highly detailed, yet attractively visualised formats. It is not for the faint-hearted, however.

Some of these, and many other great resources, can be found on the attractively designed, discerningly comprehensive, multilingual platform **Harvest Strategies**.

Books

For extensive treatment of the MSE subject, **Management Science in Fisheries: An Introduction to Simulation-Based Methods (2016)**, edited by Charles Edwards and Dorothy Dankel, is recommended.

If you are interested in learning more about a visualisation-focused approach, explore these two publications: **Visualising Uncertainty: A Short Introduction** and **Communicating Climate Risk: A Toolkit** (which includes a chapter on communicating modelling uncertainty). Both are are freely available to download.

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